

Accelerator Complex Reliability

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October, 2002

Definition of Reliability

- Military standard definition:
 - “The probability that an item will perform a required function without failure under stated conditions for a stated period of time.”
 - Note: A functional definition of failure is needed.
 - The system’s operating conditions must be stated and a period of time is needed.

Not a new concept!

- “As concerns the gold ring set with an Emerald, we guarantee that for 20 years the emerald will not fall out of the gold ring. If the emerald should fall out of the gold ring before the end of 20 years, we shall pay unto Bel-Nadin-Shumu and indemnity of 10 mana of silver.”
 - Record found on a clay tablet in Egypt – 429 BC

The Accelerator Facts

- Linac – 32 years old no upgrades to low energy part. High Energy part 10 years old.
- Linac/Booster transfer lines – upgraded in 1992 but magnets & supplies re-used so ~ 30 years old.
- Booster – magnets & vacuum systems ~ 30 years
- Anti-Proton Source (Pbar) ~ 17 years old
- Main Injector ~ the “baby” of the machines
- Tevatron ~ 19 years old

More Facts

- There are 108,000 ACNET devices in the accelerator control system.
- There are 303,000 ACNET device properties in the control system.
- There are 550 Front end computers in the control system.
- There are 320 CAMAC crates with > 6000 modules installed.

Lets get COLD!

The Tevatron Cryogenic System

- 40 Compressors totaling 27,500 HP.
- Hybrid Refrigeration system with 24 satellite refrigerators (not redundant) and two liquefiers (redundant)
- 24kW of refrigeration at 4°K
- System has the *Worlds* largest and second largest helium liquefiers (by factor of two)

Tevatron Cryogenics cont.

- 4.5 miles of liquid helium/liquid nitrogen distribution transfer line.
- > 5000 control and monitoring points
- 40,000 liquid liters of helium being circulated
- 83 pieces of rotating equipment operating at any given moment. (54 w/o installed spares)

Big Power too!

- 41 High Power ($> 1\text{MW}$) Power Supplies
- 36 Medium ($> 150\text{KW} < 1\text{MW}$)
- 79 Low Power ($> 10\text{KW} < 150\text{KW}$)
- 1049 Correction element supplies
- 21 Transistor Shunts
- 23 Kicker Supplies
- 1842 Ion Pump Power Supplies

More Power

- 27 High Voltage Supplies
- 3 High Power Pulsers
- 70 13.8KV Transformers
- 4 13.8KV Harmonic Filters
- 12 40 Mega-joule magnet dumps
- 26 Quench Protection Monitors (QPM)
- 300 Voltage to Frequency Converters (VFC)

And Support

- 265 Heater Firing Units (HFU)
- 250 Quench Bypass Switches (QBS)
- 54 Vacuum Control Crates (CIA)
- More detail available in attachments

Tools to Track Problems

- The Primary tool available to all support departments is the Downtime log and the Downtime Summary.
- This is an electronic database in which any downtime is entered by the Operations Crew.
- Available on the Beams Division Web Page for internal viewing.

Downtime Summary
Wed Aug 1 00:00:00 2001 to Tue Oct 8 13:55:51 2002
System and subsystem
with 60 minutes or more of downtime 2710.53 hrs. of DT for Interval of 10405.93 hrs.
3643 entries 0 minutes or more
Downtime/Interval= 26.05 %

Number
&
Details
TEVATRON ACCELERATOR SYSTEMS-- TQUEN
Magnet quenches (all causes) 373.98 hrs.
13.80% of total downtime (2710.53 hrs.)
3.59% of Interval (10405.93 hrs.)
146

PRE-ACC AND LINAC -- LRF
Low and High level RF systems 217.95 hrs.
8.04% of total downtime (2710.53 hrs.)
2.09% of Interval (10405.93 hrs.)
853

MAIN INJECTOR -- MIXFER
Beamline failures-> MI8,P1,P2,P3,A1,abort,Numi,etc. 146.57 hrs.
5.41% of total downtime (2710.53 hrs.)
1.41% of Interval (10405.93 hrs.)
48

TEVATRON ACCELERATOR SYSTEMS-- TCRYO
Cryo systems: frigs, compressors, etc. 145.82 hrs.
5.38% of total downtime (2710.53 hrs.)
1.40% of Interval (10405.93 hrs.)
41

Downtime Log Summary

Store Information from August 2001

Tevatron Collider Run IIA - Store Statistics

Store No.	Start of Store		End of Store		Init. Lum.		Store	Integ. Lum.		Lum. per	b*	Reason for Ending	Comment
	Date	Time	Date	Time	(E30)	Hours	(nb-1)	Hour	(cm)				
651	08/22/01	13:45	08/23/01	04:14	7.10	14.48	290.00	20.02	35	Power glitch		Feeder 47 faulted between MSS & IB1	
653	08/23/01	20:00	08/25/01	09:39	6.10	37.65	488.00	12.96	35	Lightning glitch		Dumped during end-of-store studies	
656	08/25/01	16:30	08/26/01	06:28	6.18	13.97	224.00	16.04	35	D3 QPM		Bad processor card?	
659	08/26/01	17:16	08/28/01	00:03	4.85	30.78	333.40	10.83	35	D0 SMT abort		Bad C335/336 camac module	
661	08/28/01	19:45	08/28/01	21:21	6.50	1.60	33.55	20.97	35	D11U quench		No clear reason for quench found	
665	08/29/01	11:49	08/30/01	10:47	7.40	22.97	322.50	14.04	35	Intentional		D0Q5 dropped to half value during store	
669	08/31/01	20:20	08/31/01	21:46	6.20	1.43	30.10	21.00	35	C2 PS not ready		Changed CPU board for QPM	
673	09/01/01	14:50	09/02/01	05:15	5.40	14.42	232.00	16.09	35	A2 PS not ready		Changed scaler card for QPM	
675	09/02/01	13:10	09/02/01	16:07	5.90	2.95	66.20	22.44	35	C2 PS not ready		Changed safety coordinator	
684	09/04/01	01:20	09/04/01	21:00	5.90	19.67	349.00	17.75	35	A2 PS not ready		Same old QPM problem	
686	09/05/01	10:00	09/07/01	10:23	6.90	48.38	717.30	14.83	35	Intentional			
688	09/07/01	17:33	09/08/01	16:05	7.00	22.53	399.00	17.71	35	Quench @ D48L		Reason unknown	
691	09/08/01	23:27	09/10/01	07:02	4.26	31.58	310.50	9.83	35	Intentional			
700	09/14/01	12:15	09/16/01	08:00	5.69	43.75	470.87	10.76	35	Intentional			
702	09/16/01	14:56	09/17/01	11:40	5.70	20.73	261.00	12.59	35	Intentional			
704	09/17/01	17:24	09/17/01	20:28	5.20	3.07	50.00	16.30	35	Tevatron abort		5V ps for CAMAC link repeater at B2	
706	09/18/01	01:28	09/19/01	06:10	3.00	28.70	188.00	6.55	35	Intentional			
712	09/20/01	16:11	09/21/01	09:47	5.56	17.60	268.00	15.23	35	Quench @ F46L		F4 EVUH opened too far for unk. reason	
714	09/21/01	14:50	09/23/01	09:00	7.20	42.17	566.00	13.42	35	Intentional			
716	09/23/01	11:30	09/24/01	08:19	7.50	20.82	366.00	17.58	35	E1 wet engine tripped		Controller failed -- replaced	
718	09/24/01	22:23	09/25/01	01:50	7.56	3.45	83.00	24.06	35	B0Q5 tripped		Probably QPM problem	
721	09/25/01	13:31	09/26/01	05:00	7.43	15.48	282.00	18.21	35	Intentional			
725	09/27/01	13:59	09/28/01	14:23	5.40	24.40	261.00	10.70	35	Intentional			
727	09/28/01	16:51	09/29/01	04:28	6.40	11.62	195.00	16.79	35	Quench @ B15U		B1 cold compressor tripped off	
730	09/29/01	16:16	09/29/01	19:18	6.50	3.03	57.00	18.79	35	Quench @ B15U		B1 cold compressor tripped off	
732	09/30/01	08:59	10/01/01	03:20	6.60	18.35	288.70	15.73	35	D0 SMT abort		Bad C335/336 camac module	
735	10/01/01	13:10	10/02/01	05:15	6.60	16.08	230.80	14.35	35	Intentional			
745	10/04/01	19:07	10/05/01	13:32	6.80	18.42	280.00	15.20	35	Intentional			
747	10/05/01	18:29	10/06/01	16:02	7.50	21.55	347.00	16.10	35	Intentional			
750	10/06/01	22:50	10/07/01	01:45	5.90	2.92	52.00	17.83	35	Quench @ A15U		A1 cold compressor turned off-unk. why	
784	11/28/01	20:00	11/29/01	10:00	3.20	14.00	59.00	4.21	35	Intentional		First store after M&D period	
787	11/29/01	19:03	11/29/01	21:04	3.40	2.02	25.83	12.81	35	Quench @ B15U		B1 cold compressor tripped off	
793	11/30/01	16:29	12/01/01	11:05	3.40	18.60	112.00	6.02	35	Intentional			

Tevatron Collider Run IIA - Store Statistics

Store	Start of Store		End of Store		Init. Lum.	Store	Integ. Lum.	Lum. per	β^*	Reason for Ending
No.	Date	Time	Date	Time	(E30)	Hours	(nb ⁻¹)	Hour	(cm)	
1654	08/09/02	15:34	08/10/02	07:29	13.38	15.92	447.60	28.12	35	Intentional
1656	08/10/02	10:22	08/11/02	01:35	13.30	15.22	488.90	32.13	35	A4 lead failure
1657	08/11/02	09:24	08/12/02	08:54	18.36	23.50	779.00	33.15	35	Intentional
1661	08/13/02	22:19	08/14/02	17:30	23.00	19.18	865.00	45.09	35	Intentional
1663	08/15/02	01:00	08/15/02	02:25	19.90	1.42	94.00	66.35	35	Quench @ BA,BB
1665	08/15/02	17:39	08/16/02	09:38	18.20	15.98	556.70	34.83	35	Intentional
1667	08/16/02	14:52	08/17/02	09:07	18.30	18.25	607.10	33.27	35	Intentional
1668	08/17/02	13:55	08/18/02	17:03	23.42	27.13	979.10	36.08	35	Intentional
1670	08/18/02	22:13	08/19/02	13:29	19.29	15.27	579.40	37.95	35	Intentional
1672	08/19/02	17:40	08/20/02	06:00	16.82	12.33	453.00	36.73	35	Intentional
1679	08/21/02	22:45	08/22/02	03:33	20.20	4.80	244.10	50.85	35	Ramp dump
1680	08/22/02	18:59	08/22/02	21:05	15.97	2.10	84.79	40.38	35	TeV RF tripped
1686	08/23/02	17:05	08/24/02	05:39	13.02	12.57	270.30	21.51	35	TeV quench
1687	08/24/02	14:33	08/25/02	09:29	20.60	18.93	785.00	41.46	35	Intentional
1689	08/25/02	12:08	08/26/02	06:00	20.90	17.87	814.00	45.56	35	Intentional
1691	08/26/02	09:27	08/26/02	16:15	24.30	6.80	459.10	67.51	35	TeV quench
1711	08/30/02	22:14	08/31/02	17:11	23.10	18.95	912.00	48.13	35	Intentional
1713	08/31/02	20:51	09/01/02	18:00	24.27	21.15	1045.00	49.41	35	Intentional
1716	09/02/02	00:07	09/02/02	07:17	24.70	7.17	490.30	68.41	35	C:B0Q5 tripped
1723	09/02/02	20:00	09/03/02	06:42	23.00	10.70	612.50	57.24	35	C2 wet engine
1727	09/03/02	22:27	09/04/02	08:22	21.07	9.92	557.40	56.21	35	A0 abort kickers fired
1728	09/04/02	22:55	09/05/02	15:02	18.20	16.12	647.10	40.15	35	Intentional
1730	09/06/02	03:28	09/06/02	12:04	12.58	8.60	285.20	33.16	35	Intentional
1735	09/06/02	23:23	09/07/02	23:38	22.90	24.25	900.00	37.11	35	Quench @ E11U
1737	09/08/02	08:30	09/09/02	05:00	21.65	20.50	873.00	42.59	35	Intentional
1739	09/09/02	13:00	09/10/02	07:00	19.79	18.00	541.00	30.06	35	Intentional
1748	09/12/02	03:30	09/12/02	19:45	21.40	16.25	805.00	49.54	35	Intentional
1750	09/13/02	01:24	09/13/02	19:05	25.67	17.68	1012.00	57.23	35	Intentional
1752	09/13/02	21:55	09/14/02	13:53	19.25	15.97	694.10	43.47	35	Intentional
1754	09/14/02	19:24	09/15/02	12:47	19.59	17.38	734.40	42.25	35	Intentional
1756	09/15/02	15:15	09/16/02	08:00	19.13	16.75	659.90	39.40	35	Intentional
1758	09/16/02	13:38	09/17/02	08:43	18.89	19.08	740.00	38.78	35	Intentional
1764	09/17/02	20:15	09/18/02	16:00	19.04	19.75	681.00	34.48	35	Intentional
1769	09/19/02	02:20	09/19/02	14:04	14.25	11.73	339.00	28.89	35	Intentional
1770	09/19/02	21:39	09/20/02	21:56	24.05	24.28	1098.00	45.22	35	Quench @ D0
1775	09/21/02	09:05	09/21/02	18:51	28.51	9.77	714.00	73.11	35	Quench @ D0
1779	09/22/02	07:38	09/22/02	23:33	27.59	15.92	976.00	61.32	35	Intentional
1781	09/23/02	03:30	09/23/02	12:05	28.09	8.58	656.30	76.46	35	E1 wet engine
1787	09/24/02	06:39	09/25/02	00:12	30.15	17.55	1104.00	62.91	35	Intentional
1795	09/26/02	20:36	09/27/02	17:03	23.57	20.45	997.60	48.78	35	Intentional
1797	09/27/02	22:32	09/28/02	02:09	22.95	3.62	248.60	68.74	35	Quench @ B15U
Total						4287.82	94370.73	22.01		

Collider Run IIA
03/01/01 - 10/06/02

Reason for Terminating Store:	Number of Stores Terminated	Store Hours	
Intentional	200	3463.23	
Controls	7	64.43	
Correction Magnet Systems	1	2.23	
Cryogenics	14	132.92	
Experimental Areas	3	65.76	
Glitches/Lightning	13	157.96	
Human Error	2	46.65	
Instrumentation	0	0.00	
Kickers	2	12.90	
Low Beta Quadrupoles	4	39.02	
Magnet Failure	2	26.55	
Miscellaneous	3	25.93	
Quench	9	81.52	
Quench Protection System	19	165.49	
Separators	3	8.31	
Tevatron Power Supplies	6	40.04	
Tevatron RF	3	10.45	
Utilities	0	0.00	
Vacuum	1	7.58	
There have been	292 stores with a total store time of	4350.97	hours for an average store
length of	14.90 hours		
200 stores were ended intentionally with an average store length of			17.32
hours			
92 stores were ended by failure with an average store length of			9.65
hours			
68.5% of the stores have been ended intentionally			

And the Loser Is.....

- As of 10/01/02 the largest accumulated downtime was from:
- Tevatron Accelerator Systems– TQUEN
 - Magnet Quenches (all causes)
 - WARNING be careful of what the statistics tell you! Some failures in this category were caused by the protection systems i.e. QPM or VFC that caused the magnets to quench.

A Case Study

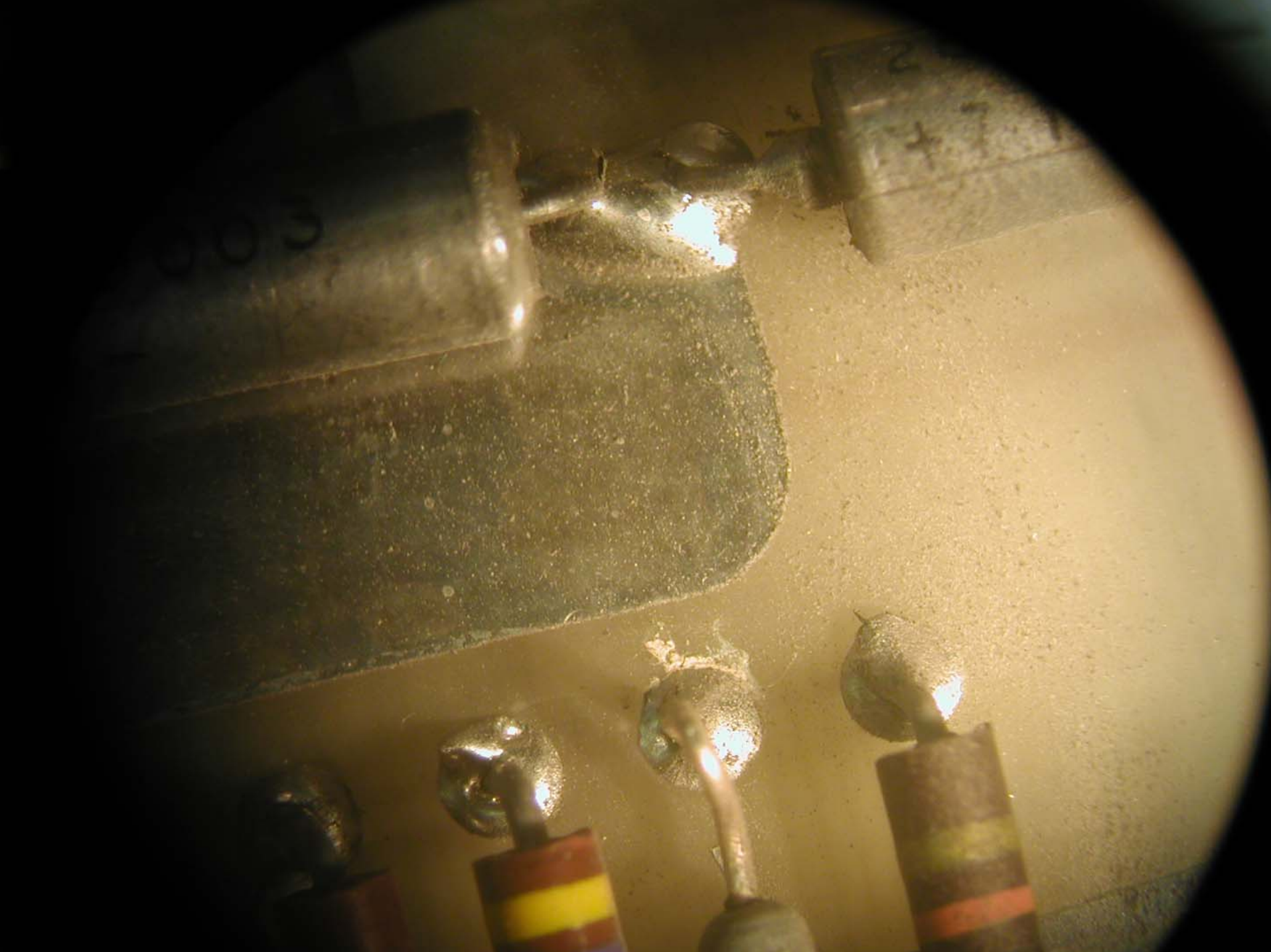
- VFCs were the cause of 10 lost stores.
 - 7 failures were in Low Beta houses where there are 45 cards installed.
 - 3 failures were in the rest of the machine where there are 204 cards installed.

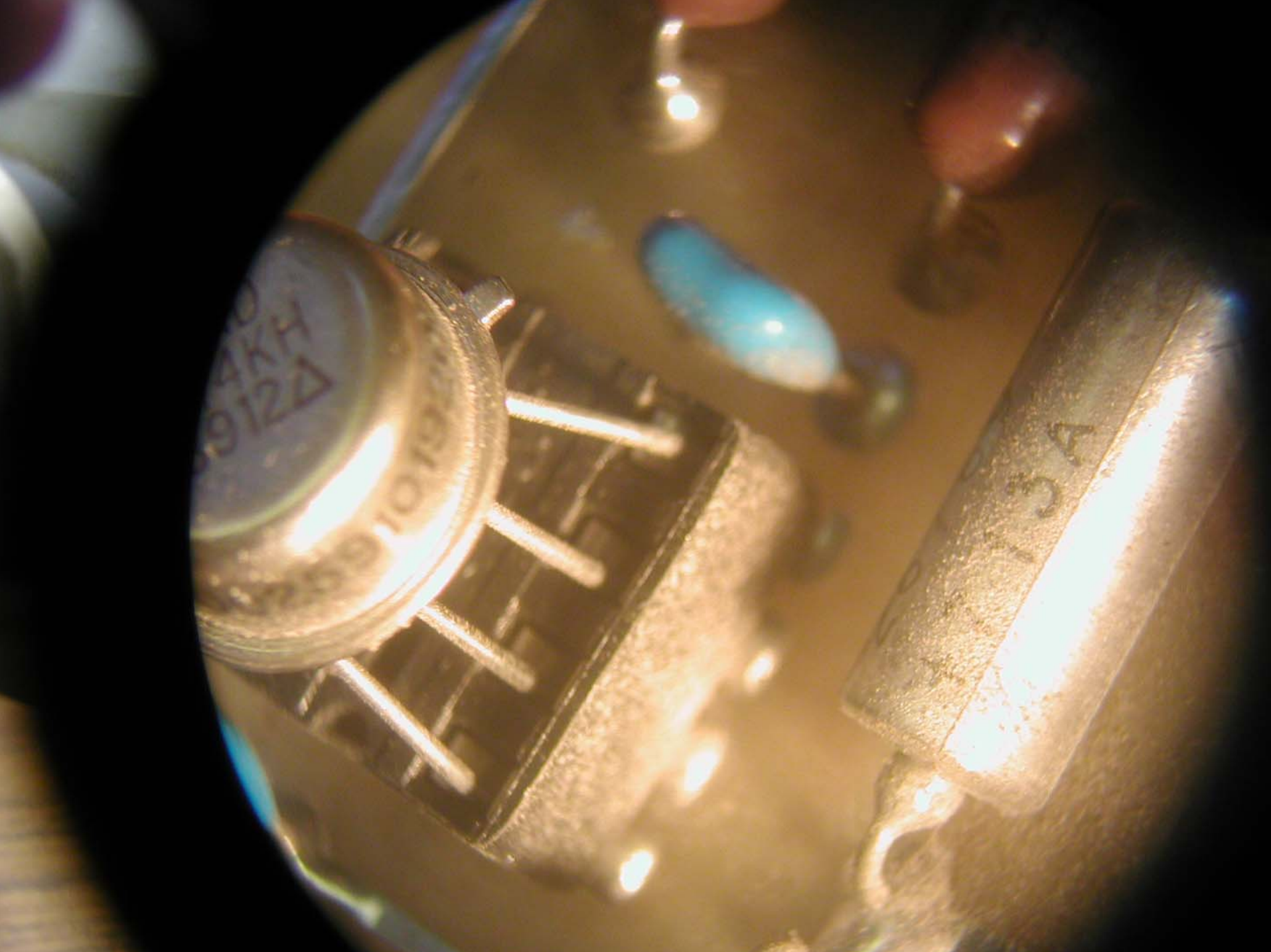
Investigation

- The VFC cards were built when the Tevatron was built ~ 1983
- Past problems pointed to high humidity as being a culprit. (50 Meg resistors)
- All of these failures happened in warm weather BUT the humidity in the buildings was low(?).

VFCs cont.

- All cards worked properly when brought back to the shop!
- All systems operated normally when the cards were replaced!
- We went 5 months last year without a failure and all failures were in warm weather.
- Let's look at the card.





10191
4KH
912Δ

3A

VFC Status

- EE Support had already changed 40 cards prior to the rash of VFC failures just based on known problems with the cards. (just didn't change them in the low beta houses yet!)
- 125 cards are in hand and are being replaced at every opportunity (down time).
- The balance of the cards have been ordered along with the parts. All cards will be replaced, and modifications made, by the January shutdown at the latest.

Not only Electronics

- The cryogenics Wet Engines have not been overhauled since the last shutdown.
- A test was performed in the past that showed a MTBF of 13,000 hours for the wet engines. All wet engines have the same time on them and will have 13,000 if not overhauled before January.
- Cryogenics department can overhaul 4 in an 8 hour shift. There are still 15 to overhaul.

How about the bigger picture?

- Given the age of many of the systems at the laboratory, obsolescence is a serious problem. We keep as many spares as possible for the systems we have and prioritize the systems that can be replaced given limited resources.

FY03 Upgrade/Rehab Items

- 1)VFC's
- 2) Wet engines
- 3) Cold Compressor Bearings
- 4) Compressor Starters
- 5) Failure of PEI water cooled transformers
- 6) Failure of Kicker Ceramic Beam Tube
- 7) Controls Equipment
- 8) Other Vulnerabilities
- See the handout for detailed status on these items

And the Future

- A Vulnerability Study was commissioned to find what items would keep us off for a *Three* month time period if they failed.
- This study generated a number of items that will require replacement based on the lack of available replacement parts. Industry no longer supports some of these.

Sample of the items identified

Component	No.	Spares	Risk	Comment
Harmonic Filter Damping Resistors	2	1	H	Requires a double failure, but could occur in either Main Injector or Tevatron (See discussion of Power Grid in Site Infrastructure section.)
Dipole PS Transformers	12	1	H	These are long-lead time items that could reduce the physics program for up to 6 months (See discussion below.)
Quad PS Transformers	6	1	H	These are long-lead time items that could reduce the physics program for up to 6 months (See discussion below.)
Main Injector Quadrupoles	269	26	M	Had a number of failures, but able to keep up with replacement rate so far (See the section on the TD/BD Study on Magnet Spares.)
Kicker Magnets	6	1	L	One spare for each type (See the general discussion below.)

Conclusion

- We take machine Reliability and Availability seriously.
- We are doing everything we can to keep the program running at the highest level of efficiency.
- We are attempting to set the proper priorities for some very expensive items.